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Water Rock Interaction [WRI 14]

In-situ and laboratory tests to evaluate the impact of water table fluctuations on stability of underground chalk mines

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Abstract

Shallow underground mines can be flooded if there is a rise in the water table, which reduces pillar strength and increases risk of collapse and surface subsidence. To prevent this, INERIS is studying rock behavior in two underground chalk mines in northern France. In the first mine, the water content of a flooded pillar is almost constant (~20%) in its internal zone, while it varies from 14% to 22% in its external zone, due to variations in the groundwater table. In the second mine, the pillar is episodically flooded and, even if no flooding occurs, the groundwater table variations cause simultaneous fluctuations of the pillar extension rates due to capillarity: from 4-5% in the middle to 10-14% in the external zone. In parallel, laboratory tests have been carried out on chalk samples. They show differences between the geomechanical behavior of these chalks: one is dolomitic and has a higher inherent strength (i.e, more resistant to water) than the other, which has a glauconitic composition.

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Keywords: water content; collapse; mechanical tests; compressive strenght; climate change; chalk; Paris basin; France.

1. Introduction

In France, there are about 500,000 known mines, and many of them are located in the chalk, limestone, or gypsum of the sedimentary Paris Basin. After abandonment, degradation occurs and internal collapses may appear and progress to the surface inducing subsidence bowls or sinkholes. Catastrophic collapses of abandoned underground mines have already occurred, particularly in the chalk of the Paris area: Château-Landon (7 deaths in 1910), Clamart (21 deaths in 1961), Chanteloup (1 death in 1991), Bagnolet (2 deaths in 1993). Most of these mines extended down to the groundwater table. Therefore, any significant

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fluctuation of the groundwater table can lead to their flooding or dewatering. The question arises whether these fluctuations can aggravate or accelerate the ageing and the degradation of the stability, especially if they become more important due to the context of climate change. The research program studies the impact of water table fluctuations on the long-term stability of chalk mines pillars, particularly in the context of climate change. We present here the experimental sites instrumented in the chalk of northern Paris Basin at Estreux (Nord) and Saint-Martin-le-Noeud (Oise), and the first results of the laboratory tests on rock samples.

2. Impact of water in the rock resistance

Rock behavior is sensitive to water content [1], especially in the case of porous rock. The increase of water content causes a decrease of the compressive strength that can exceed 50% for some type of chalk [2]. Chalk is a very porous rock (20-40%) and therefore very sensitive to changes in water content. Laboratory tests had showed that the development of cracks during saturation/desaturation cycles can produce changes in humidity [3]. In the Estreux chalk mine, it has been noted that the variations of the relative humidity of the air from 80 to 100% can saturate/desaturate the rock at the pillar surface [4].

From a hydrogeological point of view, annual cycles of groundwater recharge results in winter high water tables and summer low water tables with about metric fluctuations. However, highest amplitude cycles can occur at multi-year scales and cause flooding or dewatering of shallow underground mines.

To study this water-rock interaction, pillars were instrumented by INERIS in two underground abandoned chalk mines. Chalk samples have also been tested in the Georessources' laboratory.

3. Results of experimental sites in the chalk of Paris Basin

3.1. St-Martin-le-Noeud's mine (Oise)

This mine is about 30 m deep and contains 24 underground lakes resulting from the flooding of the lowest galleries by groundwater. A pillar located into a lake was instrumented in 2009, around 1 m above the lake level, with TDR sensors (Time Domain Reflectometry [5]) to measure the rock water content at 0.2 m and 0.9 m depth. Another sensor measures the variations of the lake water level. It is known from previous studies that these variations can attain 1 to 2 m for over a century [6]: but since 2009, the average variation was only 0.3 m and the lake level globally decreased by 0.2 m due to the actual pluri-annual drought period in northern France.

In this mine, water content is almost constant in the internal zone of the instrumented pillar (~20% at 0.9 m) while it varies from 14% to 22% in its external zone (at 0.2 m). This causes horizontal saturation gradient whose evolution is modeled on the lake level variations (Fig. 1a), indicating water penetrates to at least 0.2 m inside the pillar when the lake level rises. Nonetheless, the lateral deformation rate of the pillar does not show a significant difference between the external zone (1.1×10^{-4} at 0-0.5 m) and the internal zone (9.5×10^{-5} at 0.5-1 m). It must then be noticed that, for technical reasons, the TDR probe and the extensometer located in the external zone are not at the same depth (0.2 m and 0.5 m respectively).

3.2. Estreux's mine (Nord)

This mine is about 20 m below the surface. The groundwater level can be 2 m above and 4 m below the mine: hence it is temporarily flooded when the water rises, i.e. every 8 years on average. The pillar was instrumented in 2004 with two strain gauges (anchored respectively at 0.1 m and 0.7 m deep)

measuring its lateral horizontal extension rate due to the water table fluctuations. No flooding occurred since 2004 because of the same pluri-annual drought period as above mentioned.

In this mine, the lateral extension rate of the pillar is cyclic with marked seasonal fluctuations, in relation with piezometric cycles, from 10-14% at 0.10 m (outer zone) to only 4-5% at 0.70 m (central zone) (Fig. 1b). Moreover, the total deformation since the installation of extensometers in 2004 is fourth higher in the outer zone ($1.34x10^{-3}$) than in the central one ($3.05x10^{-4}$). This suggests that the geomechanical behavior of the pillar is also sensitive to differences in water content induced by groundwater table fluctuations, even if the mine remains in the capillarity fringe without any flooding.

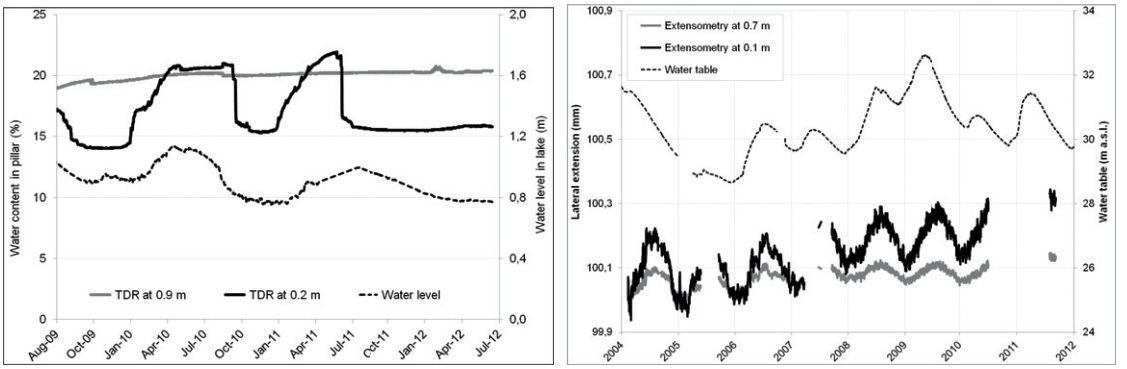

Fig. 1. Main parameters recorded in the underground mines of Saint-Martin-le-Nœud (left) and Estreux (right).

4. Laboratory tests on chalk samples

Physico-chemical parameters were determined on chalk samples from these two mines: the dry mass density (ρd), the mass density of solid skeleton (ρs), the bulk (total) porosity (n), the natural water content (W), the water saturation degree (Sr) and the carbonates ($CaCO_3$) content. The Table 1 shows that the values of bulk porosity, water content and the carbonates are significantly different for the two chalks.

Tab. 1 Physico-chemical parameters

	ρ_h (g/cm^3)	ρ_d (g/cm^3)	ρ_s (g/cm^3)	n (%)	W (%)	Sr (%)	CaCO3 (%)
EXTREUX (glauconious)	2,14	1,80	2,75	34,5	19	100	75
SAINT MARTIN (dolomitic)	2,04	1,59	2,76	41,7	27	100	85

The uniaxial and triaxial compressive strengths were measured by performing mechanical tests on cylindrical samples (ϕ = 50 mm; h = 100 mm) with an hydraulic loading press. Mechanical tests were carried out on two kinds of samples: dry samples and initially saturated samples (with aqueous solution chemically balanced with chalk in order to avoid any dissolution). A significant decrease in the strength of saturated chalks was measured (Fig. 2). This result is confirmed by other studies on similar materials [7-8-9-10]. This influence of water on the instantaneous mechanical behavior should be taken into account in the study of the long-term behavior. The chemical aspect should not be overlooked in the study of behavior of *in situ* pillars. This aspect could be significant depending on the kinetic of possible geochemical transformations due to a sudden arrival of chemically unbalanced (aggressive) water.

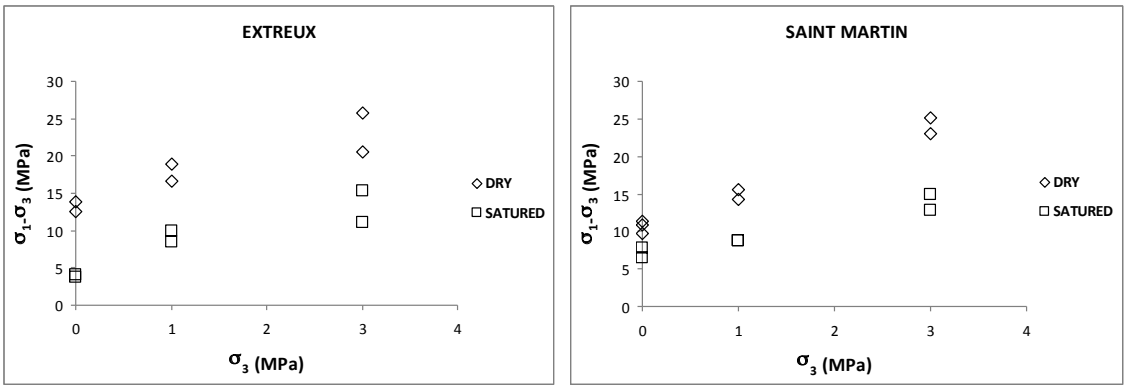

Fig. 2. Uniaxial and triaxial compressive strengths.

5. Conclusion

Some of the many French mines are partially or temporarily flooded, especially in the chalk Paris basin. One pillar has been instrumented in each of the two mines, and chalk samples have been tested in laboratory.

In Estreux' glauconious chalk, in situ measurements show the relation between groundwater table and lateral deformation, even if no flooding occurs (i.e., in capillarity fringe), in the external 0.1 m depth zone. In the most resistant dolomitic chalk of Saint-Martin, rock water content fluctuates with lake water level towards 0.2 m depth in the pillar but no significant difference can be noted in deformation rates.

Laboratory tests shows that the geomechanical behavior difference of the two chalk types, the glauconious one being more sensitive with a strong decrease of its strength resistance in relation with water content.

Recent hydrological cycles had low amplitude and show low impact on chalk pillars. According to the climate change, it could be expected a greater impact in the future with action on the aging of these abandoned mines, especially in lower resistant chalk.

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